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Broadband Clutter due to Aggregations of Fish

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FINAL REPORT
Contract Number N00014-11-M-0158

Long Term Goals

Develop an understanding of physical parameters of aggregations of fish that control clutter and produce improved scattering models that incorporate those parameters.

Objectives

This project was part of the Office of Naval Research (ONR) Basic Research Challenge formally entitled "Acoustic Uncertainty due to Marine Mammals and Fish," which was informally known as the "Fish BRC." The project was conducted in conjunction with the Naval Research Laboratory (NRL) Fish BRC project entitled "Moment-Based Physical Models of Broadband Clutter due to Aggregations of Fish," Dr. Roger C. Gauss, Principal Investigator. The focal point of the NRL project was an at-sea experiment designed to collect and analyze clutter caused by aggregations of fish, as part of the ONR effort to mitigate the effects of clutter caused by schooling fish. The primary objective of the BayouAcoustics (BA) project was to assist NRL with the planning and execution of the experiment and to assist with the interpretation of data collected during the experiment. The BA effort was concerned with determining the characteristics of fishes with the potential to cause clutter during the experiment, evaluating those characteristics, and then providing the evaluations to NRL.

The secondary objective of the BA project was to develop school target strength distributions for fish species that formed compact schools in the NRL experiment area. This was to be based on biological information acquired during the process of accomplishing the above primary objective. Target strength distributions were to be developed at frequencies near swimbladder resonance, generally below 5 kHz, and in the geometric scattering region of the fish body, generally above 5 kHz. In addition, the target strength distributions were to be used to estimate the rates of occurrence of school targets of various strengths at various frequencies in the region where the NRL experiment took place.

Approach

The approach for the primary objective was straightforward. The general time and region where the NRL experiment was to take place was determined at the start of the project. It was to be conducted during the summer of 2012 off the west coast of the United States, somewhere between northern California and Canada. The NRL experiment was to take place in conjunction with experiments conducted by other participants in the Fish BRC. Dr. O. Diachok of the Johns Hopkins University Applied Physics Laboratory (JHU/APL) was to conduct measurements aboard the same ship as NRL, while Drs. K. Benoit-Bird of Oregon State University (OSU) and D. Chu of the National Marine Fisheries Service (NMFS) Northwest Fisheries Science Center (NWFSC) were to conduct measurements on a second ship.

The first step for BA was to determine what species of fish (one or more) were likely to produce clutter where and when the experiment was scheduled. The second step was to determine the characteristics of those species that could affect the planning and conduct of the experiment. These characteristics included abundance, geographic and depth distributions, and individual and school size distributions. Reports predicting what to expect for each species were provided to NRL before their experiment. The fourth step was to participate in the NRL experiment, primarily as an advisor on fish-related issues. The final step was to determine what the pertinent characteristics of the fish actually were during the experiment and provide that information to NRL.

Acoustic scattering models that estimate the target strengths of fish schools exist for frequencies near swimbladder resonance and in the geometric scattering region. (Henceforth termed the low frequency and mid frequency models, respectively.) The first step was to determine the individual and school characteristics required for each model. Most, but not all, of this information was determined while fulfilling the primary objective. The existing model for geometric scattering used generalized school information that was replaced with information on the fish in the experimental area. This was the only change needed for this model. The near resonance model was developed for small schools of fish (100s), while the schools in the experimental area had many more fish (10,000s-100,000s). The modeling process had to be modified to account for these large numbers.

Work Completed

Fishery catch statistics are an excellent indicator of the relative abundance of commercially important species. An examination of these statistics showed that the catches of two species, Pacific sardine (*Sardinops sagax*) and Pacific hake (*Merluccius productus*), also known as Pacific whiting, were far greater than those of any other species. Because of this, they were the only species considered capable of producing significant clutter for the NRL clutter experiment.

Because of their commercial importance, fisheries research agencies expend much effort to determine the abundances of both sardines and hake in order to set fishing quotas. In the process of estimating abundances, a great deal of ancillary data is collected. These data were vital in determining the characteristics of the species that were important to the planning and execution of the NRL experiment and to the interpretation of results.

Pacific sardines form compact dense schools while Pacific hake are usually in larger, looser, aggregations. Hence, sardine schools were the more desirable clutter target and BA initially decided to focus only on them. Early in the study, BA found that, during the summer, sardines were generally about 10 to 20 nm offshore of the Washington and Oregon coasts, in water depths of about 100 ± 40 m. Based on this data, NRL initially planned to conduct its measurements in depths around 100 m. However, in the spring of 2012 it was determined that, due to environmental regulations concerning marine mammals, NRL would have to operate its acoustic sources in waters deeper than 200 m. BA had also determined that hake were abundant around 200 m.

Therefore, it was decided that BA would expand its study to include hake.

NMFS periodically conducts surveys along the west coast to survey sardines and hake. The NMFS Southwest Fisheries Science Center (SWFSC) is responsible for sardines and the NMFS/NWFSC is responsible for hake. Both Centers use essentially the same methodology. They each run east-west echo sounder transects at specified intervals along the coast to determine the geographic distribution of the species of interest and tow fishing nets to correlate species with the echo sounder data. The calibrated echo sounder data is analyzed to estimate abundance along the transects. NMFS combines the results of these surveys with other data, such as catch statistics and the results of other surveys, to estimate the abundance of the stocks. NMFS/SWFSC conducted surveys in the Pacific Northwest during the summers of 2008 and 2012. NMFS/NWFSC has been conducting such surveys for many years. Recently, surveys were conducted during the summers of 2007, 2009, 2011 and 2012.

In addition to the NMFS surveys, a sardine industry group conducted the Northwest Aerial Sardine Survey (NWASS) annually between 2009 and 2013. The principal element of these surveys consisted of small planes taking aerial photographs while flying east-west transects at specified intervals along the coast. Surface areas of sardine schools that were photographed were then measured. The second element consisted of fishing boats capturing a few selected schools while being directed by the pilots, who were simultaneously photographing the schools. These schools were weighed in order to develop a relationship between school area and weight.

The NMFS and NWASS surveys provided a wealth of data on both species. They were the primary sources of data for the BA effort. These data were analyzed in combination with other information and two reports were produced and delivered to NRL prior to the experiment. Copies were also sent to OSU, NMFS/NWFSC and JHU/APL. These reports predicted that Pacific sardine and Pacific hake would be the dominant fish that would cause biological clutter during the NRL experiment and detailed the characteristics that would be pertinent to the experiment for both species. They were:

Love, R. H., "Pacific Sardine Characteristics Affecting the Conduct of an Acoustic Clutter Experiment off the West Coast of the United States," BA TR 12-01, BayouAcoustics, Abita Springs, LA, 2012

Love, R. H., "Pacific Hake Characteristics Affecting the Conduct of an Acoustic Clutter Experiment off the West Coast of the United States," BA TR 12-02, BayouAcoustics, Abita Springs, LA, 2012.

After the experiment, data from the 2012 surveys, along with data obtained during the experiment and other information, were analyzed to show that Pacific sardine and Pacific hake were, indeed, almost certainly the species that caused biological clutter during the experiment. The report that described the situation during the summer of 2012 was sent to NRL, OSU, NMFS/NWFSC and JHU/APL. It was

Love, R. H., "Characteristics of Fishes with the Potential to Cause Acoustic Clutter off Washington and Oregon during the Summer of 2012," BA TR 14-01, BayouAcoustics, Abita Springs, LA, 2014.

The report written after the experiment is quite similar to those written before it but it could be more specific with regard to the locations where NRL chose to conduct its measurements. It contains updated fishery information and some results from the experiment. Therefore, only the BA analysis and results produced for the 2014 report are discussed below.

Figure 1 shows the catches of important commercial fish off the west coast of the United States since 2000. The catch of hake has been well above any other species in every year. In 2012, the hake catch was relatively low compared to other years. The catch of sardines was much higher than any species other than hake in every year until 2014. In 2012 the catch of sardine was relatively high but has decreased significantly in the last two years.

Figure 2 shows estimations of sardine abundance made annually between 2007 and 2014. The estimates differ because, each year, abundances are back calculated based on updated models and the most current data. The three estimates since 2012 all show that sardine abundance has been steadily decreasing since 2006.

Figure 3 shows estimations of adult female hake abundance between 2009 and 2014. Assuming that males comprise about half the population, total abundances are about double those shown in the figure. Except for 2011, all the estimates generally agree. The 2013 and 2014 estimates indicate that the hake population is increasing.

Figure 4 shows the NRL experiment area. The NRL ship, the R/V New Horizon, was allowed to stand off in waters deeper than 200 m and propagate signals into shallower water. As long as NRL was not conducting clutter measurements, the ship was allowed to sail closer to shore.

OSU and NMFS/NWFSC conducted acoustic measurements on hake and squid in the vicinity of the NRL experiment area. During the experiment, BA kept in regular contact via e-mail with OSU to obtain essentially real-time data on hake and kept in daily contact with NWASS personnel via phone to determine the status of the NWASS survey and the locations of the commercial sardine fishing fleet.

The New Horizon was equipped with a dual frequency Simrad scientific echo sounder. BA took charge of operating this equipment. Figure 5 shows a nighttime echo sounder record of sardine-like targets. Figure 6 shows two daytime echo sounder records of hake-like targets. (Fish cannot be identified with absolute certainty with acoustic data only. That is why fisheries agencies always supplement their acoustic surveys with fish capture.) OSU and NMFS/NWFSC, who have a great deal of experience with echo sounding in the Pacific Northwest, assisted BA in the identification of hake aggregations.

Figures 7, 8 and 9 show the geographic distributions of sardines observed by NWASS and NMFS/SWFSC and hake observed by NMFS/NWFSC. These figures show that sardines and hake were abundant in the NRL experiment area during the summer of 2012.

The surveys found sardine schools from 3 nm to 30 nm from shore, with average near shore and offshore distances of 9 nm and 20 nm, respectively. Average near shore and offshore bottom depths over which sardines were found were 85 m and 280 m, respectively. The New Horizon Simrad data fell within these limits.

The NWFSC survey found hake from about 10 nm to 35 nm from shore. Very few were found over bottom depths less than 200 m; most were between 300 m and 600 m. The OSU/NWFSC experiment consistently found hake between 200 and 450 m. The New Horizon saw hake-like targets over bottoms greater than 200 m, never shallower.

Daytime depths of sardine schools captured during NWASS surveys range from near the surface to just below 20 m. The average depths of the tops and bottoms of the schools were 4 m and 10 m, respectively. At night the New Horizon saw sardine-like targets in the upper 10 m to 30 m.

Hake depths are more closely related to distance above the bottom, rather than distance below the surface. Depths varied significantly, but most hake were more than 100 m to 200 m deep and 50 m to 100 m above the bottom.

NWASS carefully measured the surface area of each photographed school. BA converted these areas into equivalent circular diameters (ECD). Figure 10 shows the distribution of school sizes measured by NWASS in 2012. School ECD range from 10 m to 110 m, with the mode at 20 m and the mean at 29 m.

Daytime echo sounder records of hake showed that they were often in wavy layers of varying intensity. The layers were 10 m to 40 m thick and extended for miles. At night the hake dispersed vertically but their mean depth did not change significantly.

Along with measuring the surface area of each sardine school that was captured, NWASS measured the weight of each. They also took a sample of 50 fish from each school and measured their weights and lengths. In 2012 the mean size of a sardine was 23 cm and 150 gm.

Hake captured in trawls by NMFS and OSU were sampled and measured. It was determined that two age groups with mean lengths of 32 cm and 40 cm were present during the NRL experiment.

The information about the characteristics of sardines and hake relating to the NRL experiment that has been synopsized above was compiled and sent to NRL in November 2014. This compilation will comprise the bio-acoustics section of the journal article that Dr. Guass and his staff are writing on the results of the experiment. In addition, BA co-authored two presentations on the experimental results that Dr. Gauss made at Acoustical Society of America meetings.

The NWASS catch data were of minor interest to NRL but they were crucial for BA's secondary objective. The mid frequency school target strength model requires the mean length of an individual fish, the size distribution of the schools, and the packing density (or spacing) of the fish in the school. NWASS provided BA with raw data on all captured schools. The mean length and weight of the sampled fish from a school were determined as were the means of all sampled fish. Knowing the weight of a school and the mean weight of an individual allowed the number of fish in each school to be determined. To determine packing densities, the volume of the schools had to be determined. NWASS data provided school area and thickness but that was not enough to determine volume. School shape had to be estimated. Horizontal shape was determined from photographs of hundreds of schools kindly provided by NWASS to BA. For modeling purposes, it was decided that the best simple shape was one with straight parallel sides and rounded ends. Information from NWASS pilots indicated that the schools were essentially flat on top, except near the edges, which were deeper. Thus, the vertical shape was also assumed to be flat with rounded ends. Having a basic shape, packing densities could be calculated. Figure 11 shows the packing density/school size distribution. Packing densities were binned into seven bins ranging from 0.13 to 1.50 fish/body length cubed (F/L^3). (For a 23 cm fish, 1 F/L^3 is equivalent to 82.2 F/m^3.) Figure 11 shows that small schools are generally more densely packed than larger ones.

The data in Figure 11 can be used to calculate the numbers of fish in a school for each of the 45 packing density/school size combinations. Numbers range from about 5000 to over one million. Multiplying these numbers by the mean fish weight of 150 gm gives the weight of each combination. Weights range from under 1 mt to almost 170 mt. By combining school weights with the values in Figure 11, the weight of 10,000 schools was calculated: 246934 mt. An estimated sardine abundance of about 6.6 million mt (shown in Figure 2) results in approximately 26,700 schools of Pacific sardine inhabiting the waters off Oregon and Washington during the summer of 2012.

The area over which sardines were abundant was about 7000 km^2. If the schools had been uniformly distributed throughout this area (which the aerial photographs show was not true), there would be about 4 schools/km^2.

The low frequency school target strength model requires two additional pieces of information. The resonance frequency of a swimbladder depends on its size and its depth. The depth range of sardine schools is available from the NWASS school capture data. Unfortunately, when NWASS measured the sizes of individual sardines, they did not examine their swimbladders. Thus, information on swimbladders had to be obtained elsewhere. No data on sardine swimbladders could be found but there are data on herring swimbladders. Herring are closely related to sardines, so these data were used. Both herring and sardine swimbladders compress with depth. Some information on herring indicate that their swimbladders are “over-pressurized” at the surface, so it was necessary to decide what the proper sizes of sardine swimbladders were at depth.

At this point, all the biological parameters needed for the acoustic models were compiled. However, due to the vagaries of sequestration, the acoustic modeling was split from this contract and was funded under a separate purchase order: ONR Purchase Order N00014-13-P-1221, entitled “Target Strengths of Pacific Sardine Schools at Low and Mid Frequencies”. Work under this Purchase Order is on-going.

As an adjunct to the initial objectives, it was decided to examine the possibility of applying the results of the project to an area of tactical interest. Two potential regions were chosen: around Korea and the Arabian Sea. United Nations Food and Agricultural Organization (FAO) data on statistics of fish catches by ocean area, species and country from 2006 through 2012 were used. The FAO areas are very large. Area 51 includes the Indian Ocean west of India. Area 61 includes the northwest Pacific Ocean, the Sea of Okhotsk, the Sea of Japan, the Yellow Sea and the East China Sea. Many countries have significant catches in Area 51 but only but Russia, Japan, South Korea, China and Taiwan have significant catches in Area 61. It was an easy decision to choose Area 61. Hundreds of fish species are caught in Area 61. Using a set of criteria to eliminate species reduced hundreds of species to 27, then 13, and now to 5 with the potential to cause significant clutter in the Sea of Japan around Korea. They are Japanese anchovy, Japanese pilchard, Pacific (chub) mackerel, Japanese jack mackerel, and Pacific saury.

The characteristics of these species that are required for acoustic modeling are the same as those needed for Pacific sardines. The idea is to estimate these characteristics based on the current work on Pacific sardine and older work on Northern anchovy. Further work here depends on the results of the acoustic modeling of sardine schools.

Summary

Effort on the first objective, assisting NRL with planning and execution of the experiment and assisting with the interpretation of data collected during the experiment has been successfully completed.

Effort on the second objective, modeling school target strength distributions, has been partially completed: all of the biological components required for acoustic modeling have been developed. The acoustic modeling has been passed to another project to complete.

References

<u>Reports</u>

1. Love, R. H., "Pacific Sardine Characteristics Affecting the Conduct of an Acoustic Clutter Experiment off the West Coast of the United States," BA TR 12-01, BayouAcoustics, Abita Springs, LA, 2012
2. Love, R. H., "Pacific Hake Characteristics Affecting the Conduct of an Acoustic Clutter Experiment off the West Coast of the United States," BA TR 12-02, BayouAcoustics, Abita Springs, LA, 2012.
3. Love, R. H., "Characteristics of Fishes with the Potential to Cause Acoustic Clutter off Washington and Oregon during the Summer of 2012," BA TR 14-01, BayouAcoustics, Abita Springs, LA, 2014.

<u>Presentations</u>

1. Gauss, R. C., J. M. Fialkowski, and R. H. Love, "Clutter statistics of long-range wideband echoes from fish aggregations off the Oregon coast," 166th Meeting of the Acoustical Society of America, San Francisco, CA, December 2013.
2. Gauss, R. C., J. M. Fialkowski, and R. H. Love, "Spatiotemporal variability of clutter due to fish aggregations in the vicinity of Hecate Bank," 167th Meeting of the Acoustical Society of America, Providence, RI, May 2014.

<u>Journal Article</u>

The bio-acoustics section of a journal article being written by Dr. Guass and his staff on the results of the experiment was completed and sent to NRL. The title and journal are still to be determined by Dr. Gauss.

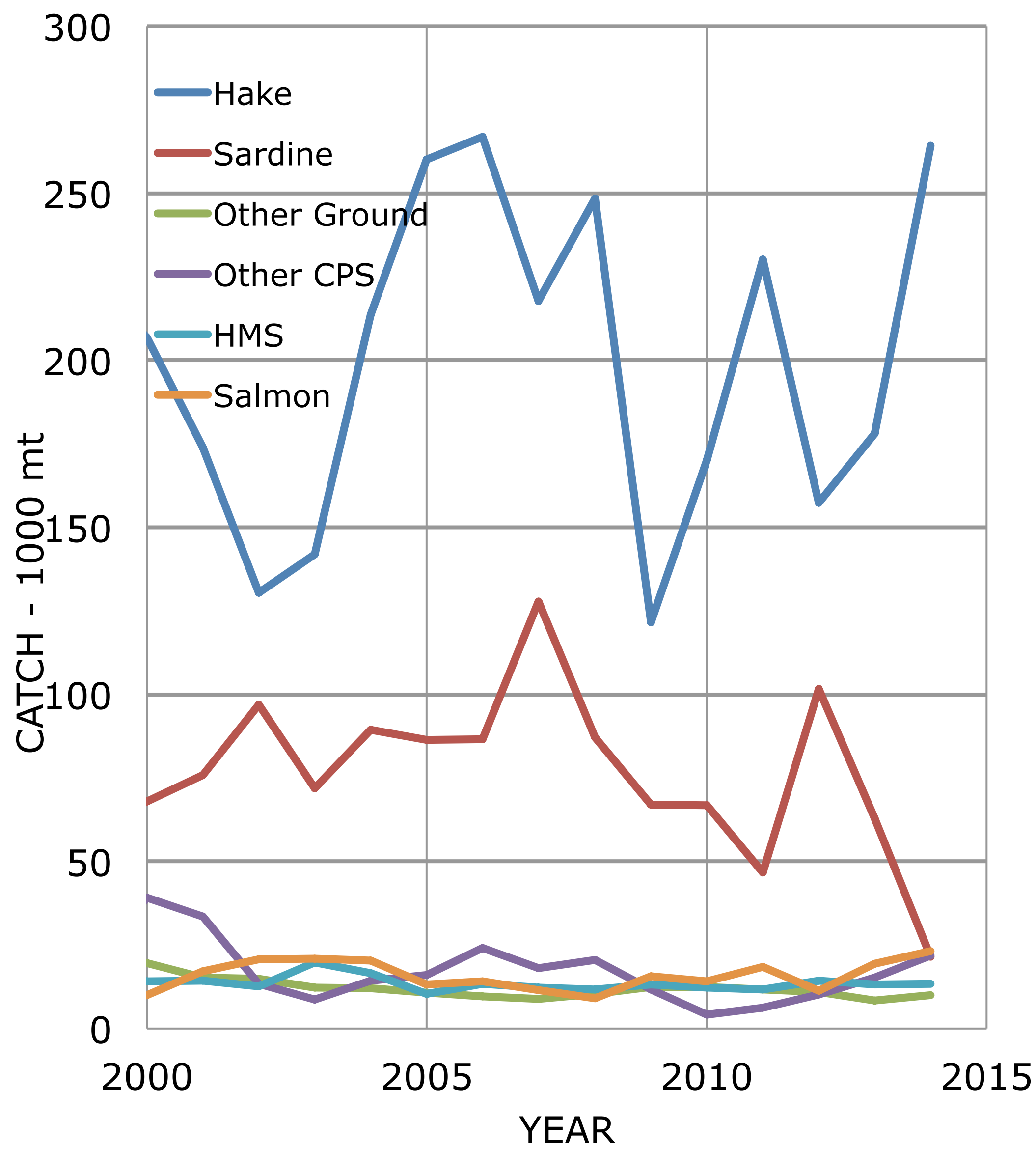


Figure 1 - Fish catches off the U. S. West Coast. Other Ground includes cods,rockfishes, sablefish, grenadiers, and pollock. Other CPS (Coastal Pelegic Species) includes anchovy, herring, and mackerels. HMS (Highly Migratory Species) includes tunas and bi

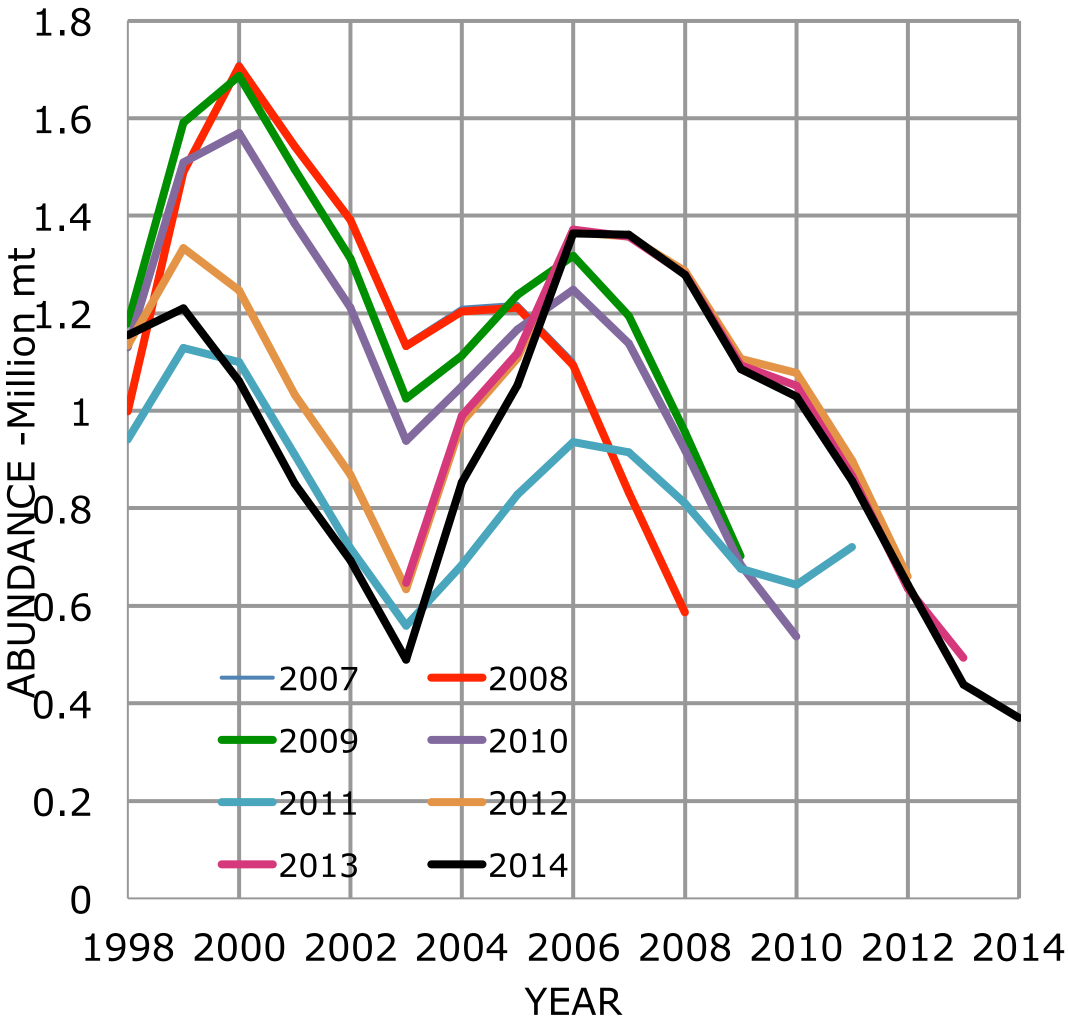


Figure 2 - Estimations of Pacific sardine abundance

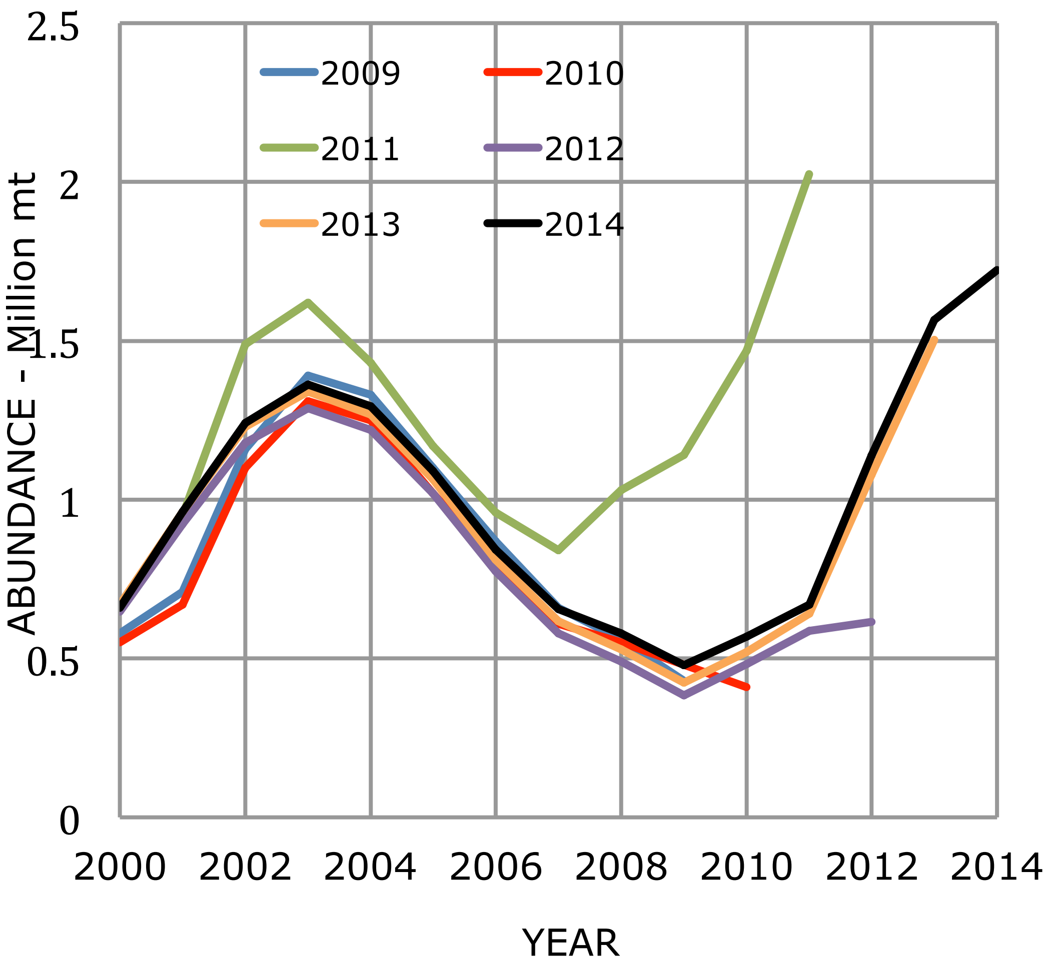


Figure 3 - Estimations of Pacific hake spawning female abundance

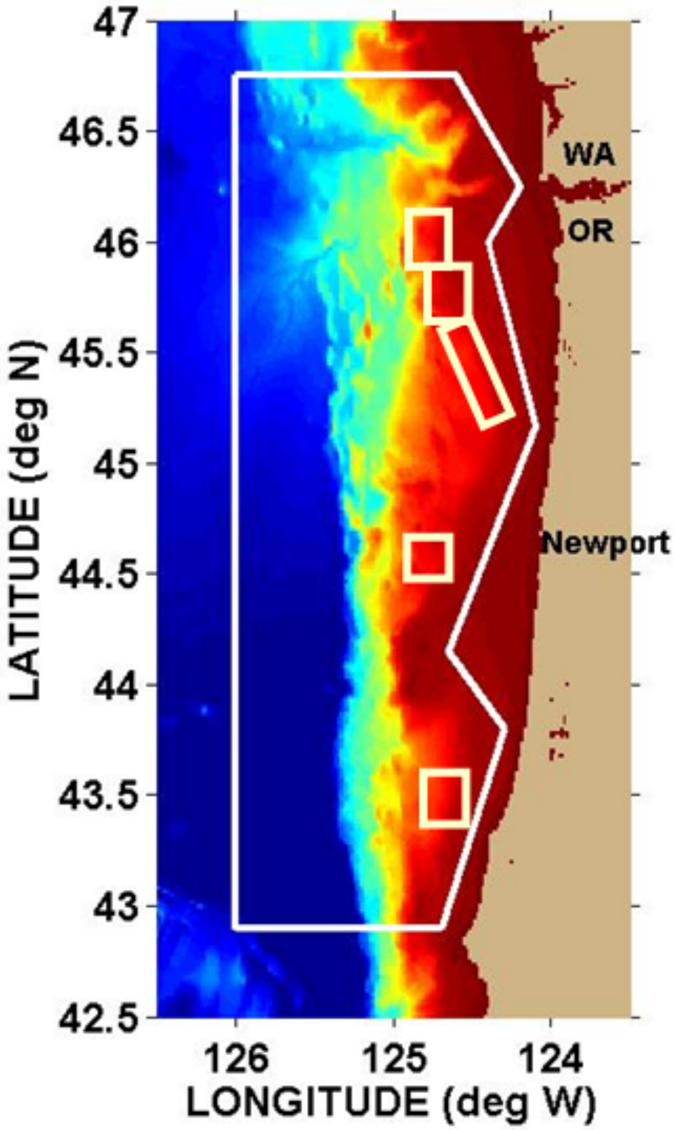


Figure 4 – NRL Experiment Area. The large, ragged, box indicates where NRL was allowed to conduct its acoustic measurements. The small rectangles indicate where NRL actually conducted measurements.

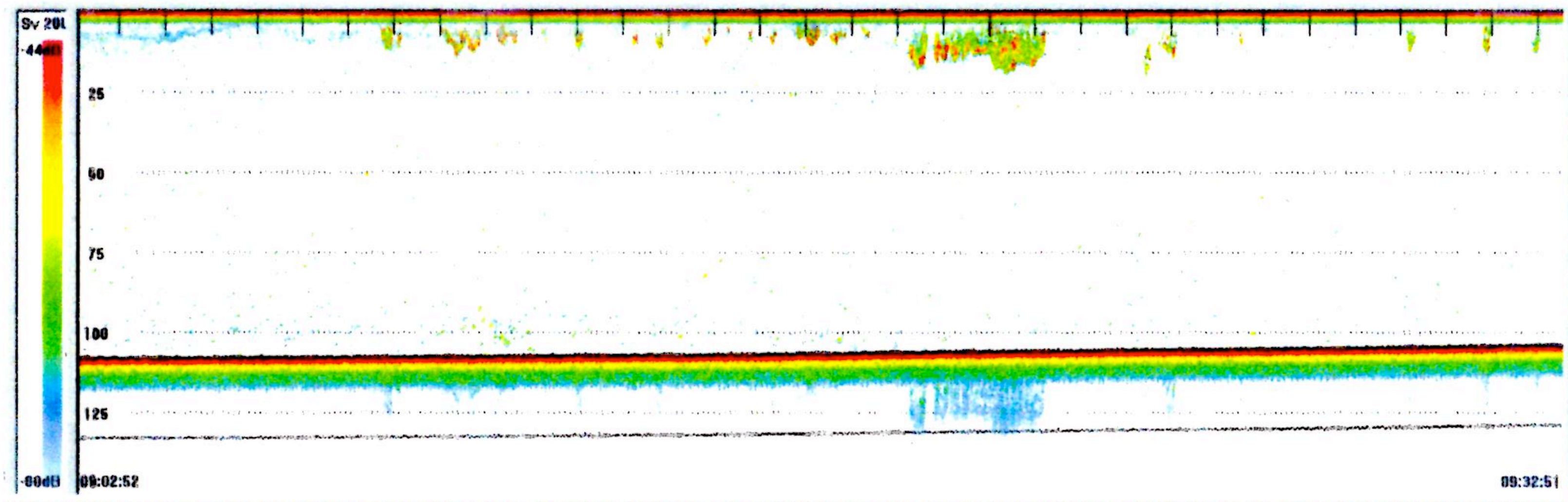
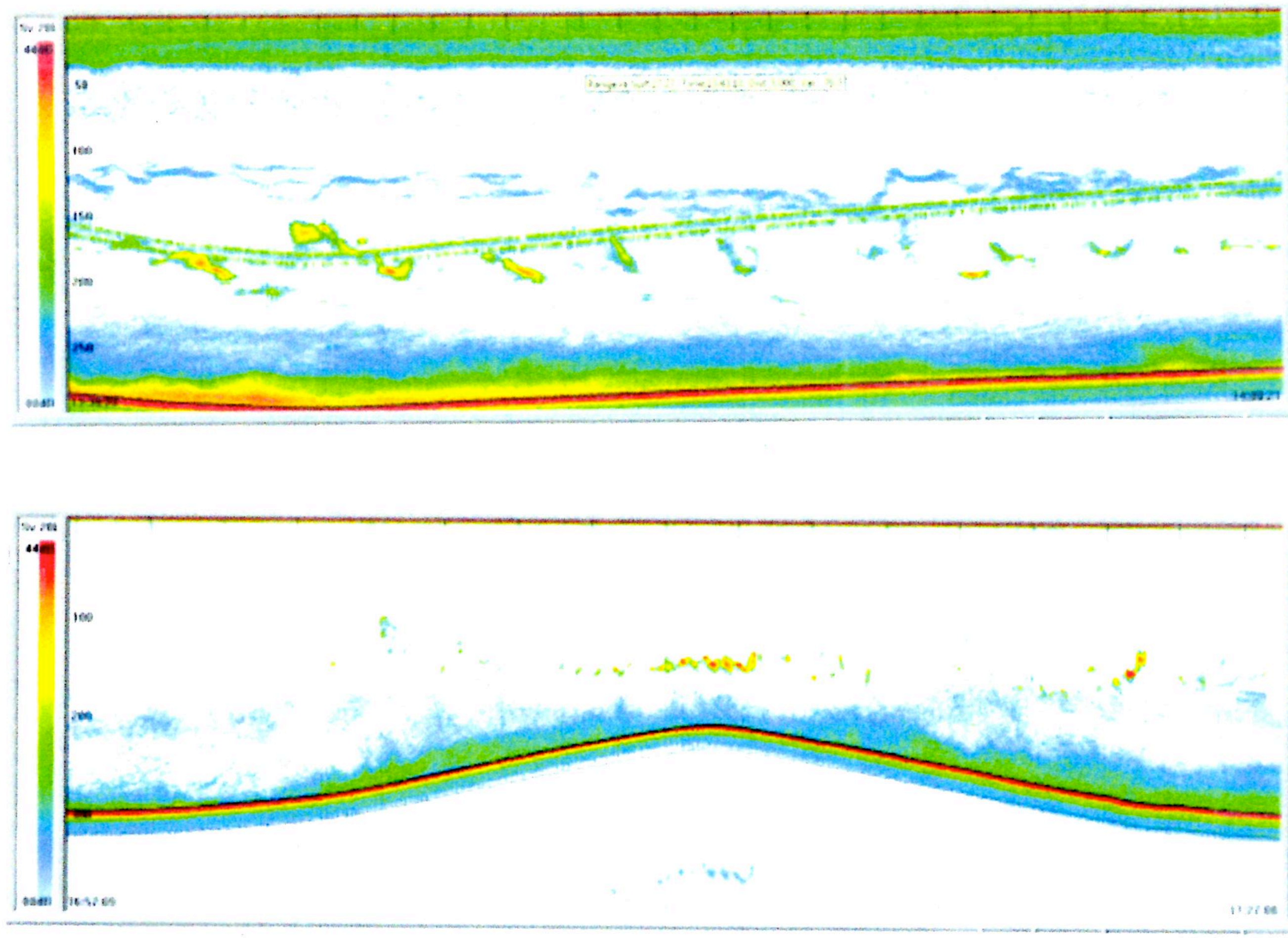


Figure 5 – New Horizon nighttime 38 kHz echo sounder record showing high concentrations of sardine-like targets. Ship speed was 7 kt.



(a)

(b)

Figure 6 – New Horizon daytime 38 kHz echo sounder records showing high concentrations of hake-like targets. (a) Ship speed was 3.5 kt. (b) Ship speed was 10.5 kt.

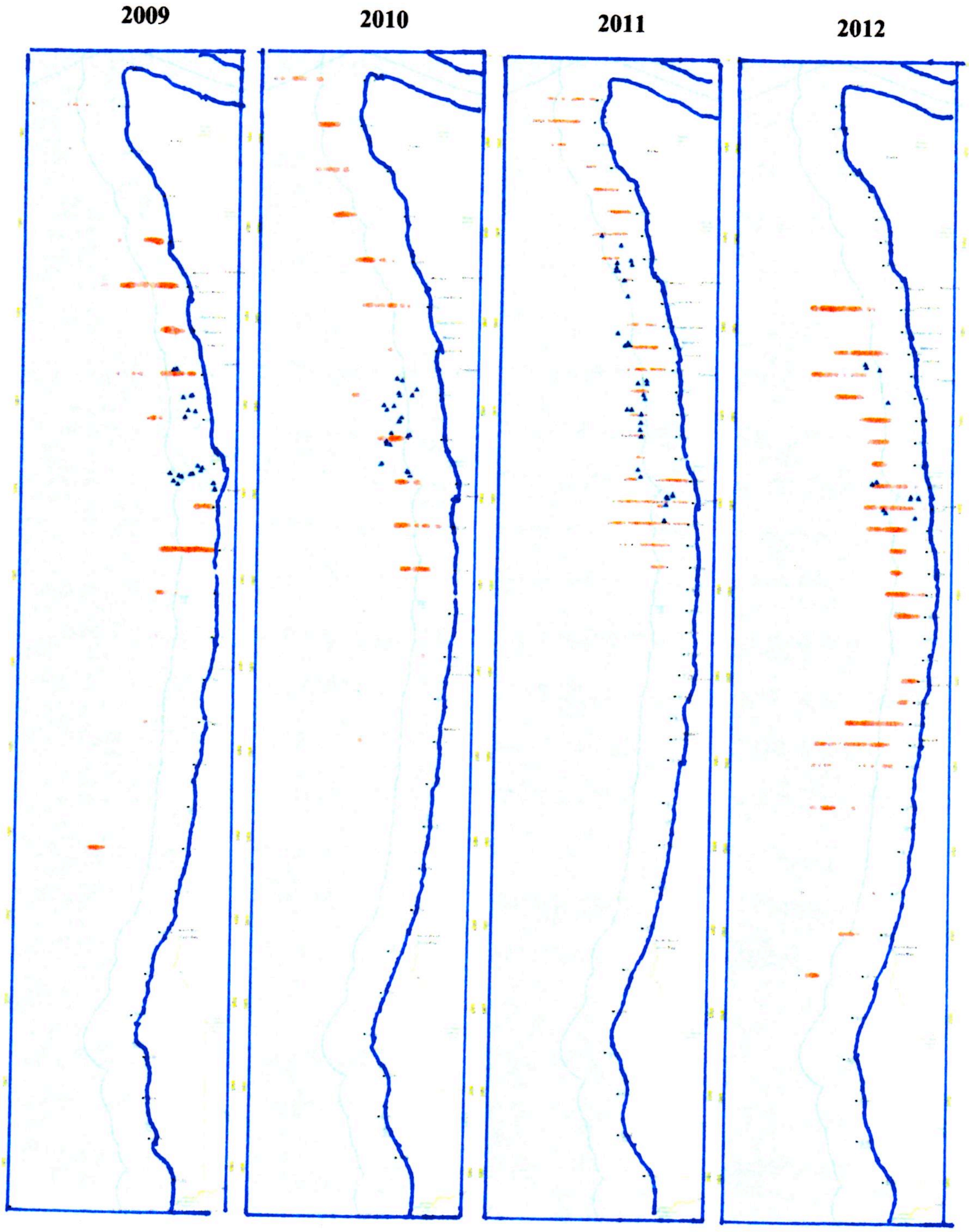


Figure 7 – Summertime geographic distributions of Pacific sardines, as determined by NWASS. Orange dots are school locations. Blue dots are locations of school captures. (Reprinted with permission of NWASS)

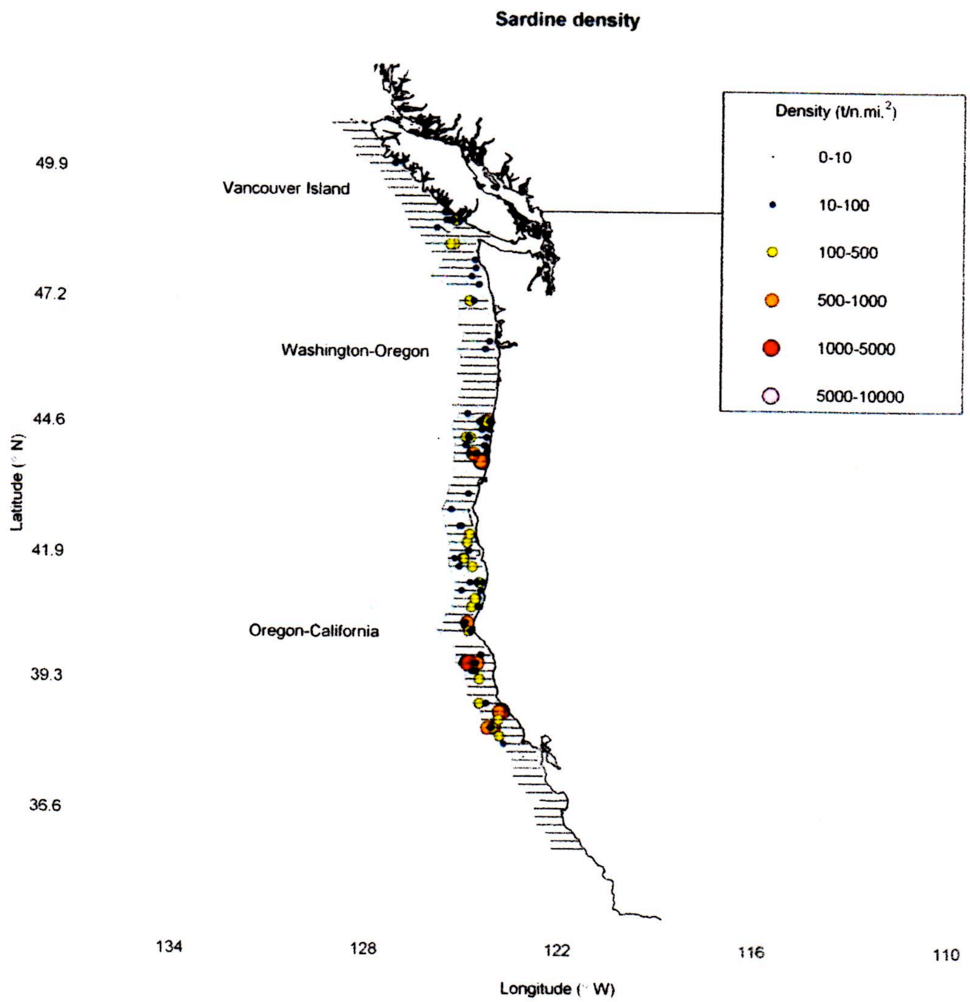


Figure 8 – Summertime geographic distributions of Pacific sardines, as determined by NMFS/SWFSC. (Reprinted with permission of NMFS/SWFSC)

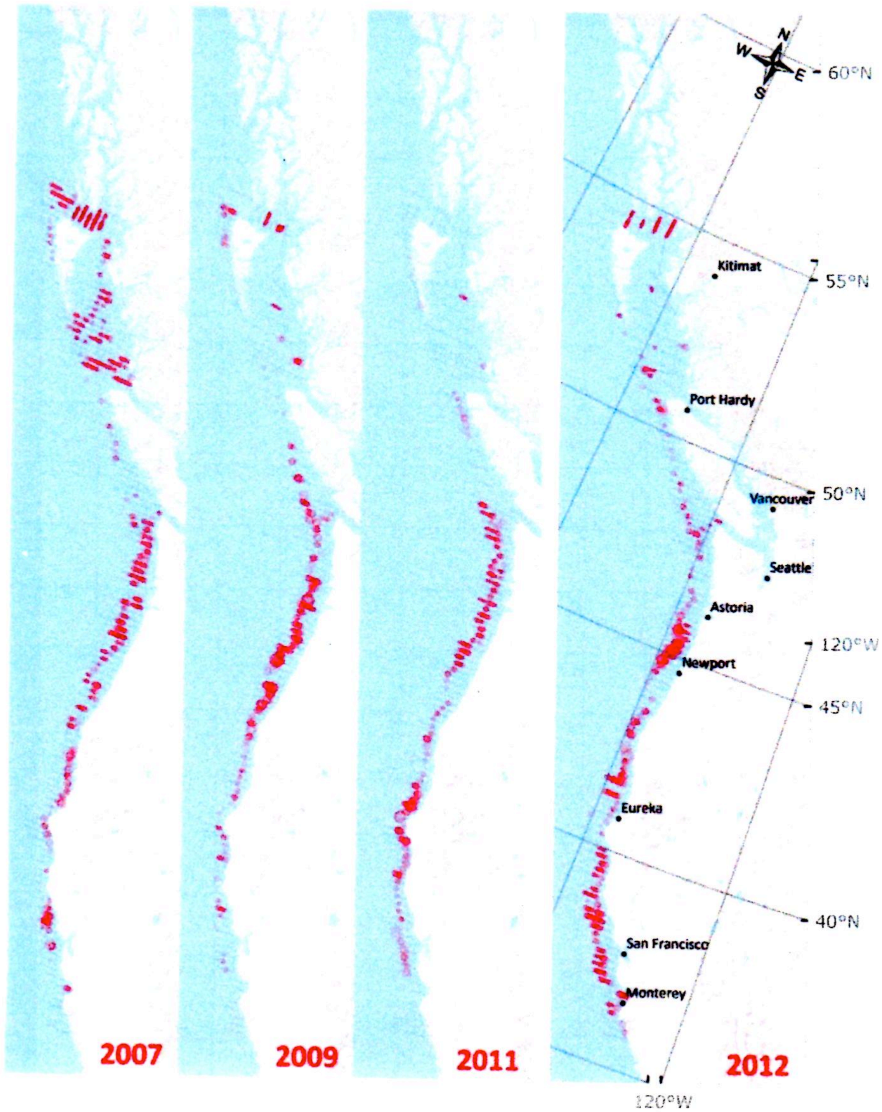


Figure 9 – Summertime geographic distributions of Pacific hake, as determined by NMFS/NWFSC. (Reprinted with permission of NMFS/NWFSC)

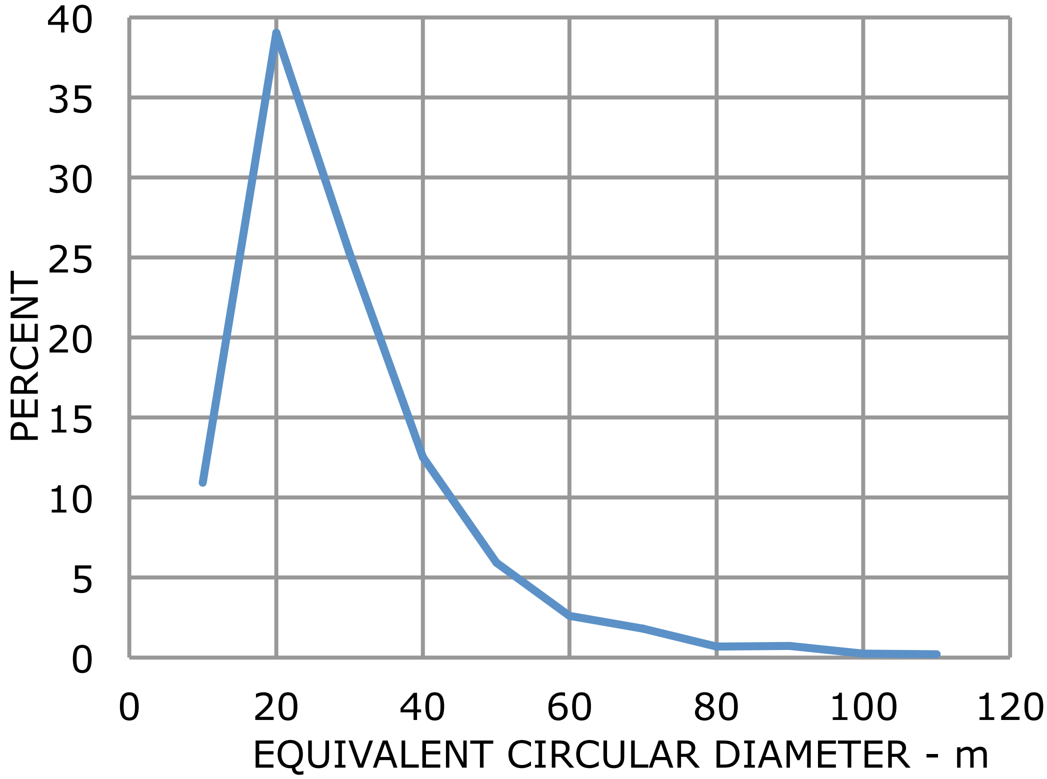


Figure 10 - Size distribution of Pacific sardine schools in 2012, as determined by NWASS

Figure 11 – Estimated sardine school size-density distribution for 10,000 schools

Equivalent School Diameter	Number of Schools Density - Fish/L^3						
m	0.13	0.19	0.29	0.41	0.59	0.91	1.50
10		107	201	242	281	362	147
20		320	600	720	840	1080	440
30		189	354	425	495	637	260
40		104	218	287	334	207	
50		108	146	178	108		
60		52	70	86	52		
70		46	60	42	22		
80	21	28	21				
90	18	24	18				
100	15	15					
110	10	10					

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